PREDICTION OF GRINDING MACHINABILITY WHEN GRIND ALUMINIUM ALLOY USING WATER BASED ZINC OXIDE NANOCOOLANT

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ABSTRACT

This thesis deals with the prediction of grinding machinability when grind aluminium alloy using water based zinc oxide nanocoolant. The objective of this thesis is to find the optimum parameter which was the depth of cut, investigate the surface roughness and wear produced during experimental and develop the prediction model with the usage of Artificial Neural Network (ANN). The work piece used was aluminium alloy and zinc oxide nanocoolant as the grinding coolant. The grinding process was carried out with the usage of silicon carbide as the grinding wheel. The design of experiment was nine experiments for each single and multi-pass. The parameter used in this study was various depth of cut. The thesis describes the effect of coolant on the surface roughness and also the wheel wear. As a result, the usage of nanocoolant lead to the decrease in the surface roughness and also the wheel wear. The 2D microstructure of the grinded material was observed to view the material condition for various depth of cut. The surface roughness for grinding process using nanocoolant has a better result compared to water based coolant. Next, the result was trained using ANN to develop the prediction model for various depth of cut. Basically, the surface roughness became constant at one point with the increasing of depth of cut, whereby plastic deformation occurs. To conclude this study, the objective of the study was achieved, 1) the optimum depth of cut was 5µm, 2) the surface roughness of the material was investigated, whereby the roughness increase with the increasing of depth of cut and 3) the prediction model was done with ANN. As for the recommendation, the usage of different type of nanocoolant with various concentration and different particle sizes may affect the surface roughness of the material and also the wear produced. Next, the usage of different type and size of wheel should be considered in order to obtain a better surface finish.

ABSTRAK

Tesis ini membentangkan ramalan pengisaran di mesin apabila mengisar aloi aluminium menggunakan zink oksida nanocoolant berasaskan air. Objektif tesis ini adalah untuk mencari parameter kedalaman potongan yang optimum, menyiasat kekasaran permukaan dan kehausan roda yang dihasilkan semasa eksperimen dan membangunkan model ramalan dengan penggunaan Artificial Neural Network (ANN). Bahan kerja yang digunakan adalah aloi aluminium dan cecair penyejuk nano zink oksida sebagai penyejuk pengisaran. Proses pengisaran dijalankan dengan penggunaan silikon karbida sebagai roda pengisaran. Reka bentuk eksperimen adalah sembilan eksperimen bagi setiap laluan tunggal dan pelbagai. Parameter yang digunakan dalam kajian ini adalah pelbagai kedalaman potongan. Tesis ini menerangkan kesan penyejuk pada kekasaran permukaan dan juga kehausan roda. Hasilnya, penggunaan cecair penyejuk nano membawa kepada penurunan dalam kekasaran permukaan dan juga kehausan roda. 2D Mikrostruktur terhadap bahan yang dikisar diperhatikan untuk mengkaji keadaan bahan bagi pelbagai kedalaman potongan. Kekasaran permukaan untuk proses menggisar menggunakan cecair penyejuk nano mempunyai hasil yang lebih baik berbanding penyejuk berasaskan air. Seterusnya, keputusan telah dilatih menggunakan ANN untuk membangunkan model ramalan untuk pelbagai kedalaman potongan. Pada asasnya, kekasaran permukaan menjadi malar pada satu titik dengan peningkatan kedalaman potongan, di mana ubah bentuk plastik berlaku. Sebagai kesimpulan kajian ini, objektif kajian telah dicapai, 1) kedalaman optimum potongan adalah 5µm, 2) kekasaran permukaan bahan yang telah disiasat, di mana kekasaran permukaan bahan meningkat dengan peningkatan kedalaman pemotongan dan 3) ramalan model bagi pelbagai kedalaman potongan dicapai dengan ANN. Sebagai cadangan, penggunaan cecair penyejuk nano yang berlainan jenis dengan kepekatan yang pelbagai dan saiz zarah yang berlainan mungkin memberi kesan kekasaran permukaan bahan dan juga kehausan roda yang dihasilkan. Seterusnya, penggunaan roda pengisaran yang berlainan jenis dan saiz perlu dipertimbangkan untuk mendapatkan kemasan permukaan yang lebih baik.

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LIST OF SYMBOLS

k_{nf}	Thermal conductivity of nanoparticle
k_w	Thermal conductivity of water
Cp	Heat capacity
Ra	Roughness average
Rz	Arithmetic mean
Rq	Root-mean-square average
T_{nf}	Nanoparticle temperature
d_p	Nanoparticle diameter
ρ_w	Density of water
ρ_{nf}	Density of nanoparticle
C_w	Specific heat of water
μ_w	Viscosity of water
μ_{nf}	Viscosity of nanoparticle
ω	Weight percent
ϕ	Volume percent
q	Constant heat rate

LIST OF ABBREVIATIONS

AA	Aluminium Alloy
Al	Aluminium
ZnO	Zinc Oxide
Al_2O_3	Aluminium Oxide
TiO_2	Titanium Oxide
CuO	Copper Oxide
SiC	Silicon Carbide
Cr	Chromium
Cu	Copper
Fe	Ferum
Mg	Magnesium
Mn	Manganese
Si	Silicon
Ti	Titanium
Zn	Zinc
ANN	Artificial Neural Network
RMS	Root-Mean-Square
AD	Average Deviation
SD	Standard Deviation
VLD	Validation
TRN	Training
TST	Testing

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Grinding is a precision machining process which is widely used in the manufacture of components requiring fine tolerances and smooth finishes. This research studied the prediction of grinding machinability when grind aluminium alloy using water based zinc oxide nanocoolant. Cutting fluids are used in grinding for a variety of reasons such as improving wheel life, reducing work piece thermal deformation, improving surface finish and flushing away chips. Large fluid delivery and cooling systems are evident in production plants.

High rates of manufactured items have been machined by grinding at some stage of their production process, or have been processed by machines whose precision is a direct result of abrasive operations. However, even being the grinding process the most used in industry for obtaining high level of surface quality, it remains as one of the most difficult and least understood processes (Eastman et al., 2001). That maybe has origin in the mistaken faith the process is extremely complex to be understood due to the large number of cutting edges and irregular geometry, high cutting speed, and very small depth of cut which varies from grain to grain.

Nanocoolant is a new class of fluids engineered by dispersing nanometer-size solid particles in base fluids to increase heat transfer and tribological properties. The thermal conductivity and the convection heat transfer coefficient of the fluid can be largely enhanced by the suspended nanoparticles (Bin Shen, 2008). Coolants with nanoparticle additives exhibit improved load-carrying capacity, anti-wear and friction reduction properties. These features make the nanocoolant very attractive in some cooling and/or lubricating application in many industries including manufacturing, transportation, energy, and electronics.

1.2 PROBLEM STATEMENT

Grinding is recognized as one of the most environmentally unfriendly manufacturing processes. An extensive amount of mist is generated during grinding, and the problem is exacerbated by the use of high wheel speeds. The mist generation rate in grinding is often an order of magnitude higher than that in turning. Millions of workers are engaged in daily manufacturing operations worldwide. However, the health hazards to machine operators and other nearby workers who breathe in this hazardous mist are often overlooked. As environmental regulations get stricter, the cost of disposal or recycling continues to go up. The need for cost-reduction has all promoted the development of new environmentally conscious machining processes.

Cutting fluids are a critical factor in controlling these undesirable effects of elevated temperatures, thermal damage, and dimensional inaccuracies (Khettabi et al., 2010). Cutting fluid reduces the machining power and the associated heat generation, while also enhancing surface quality and reducing wheel wear. Cooling by the fluid removes heat from the tool and the work piece. As an alternative, the recent development of nanocoolants replaced cutting fluids which can be used in grinding. The nanocoolants properties of advanced heat transfer, thermal conductivity and viscosity can provide better cooling and lubricating in the grinding process, and make it production-feasible. The suitable depth of cut is also needs because it can affect the surface texture been rougher and the surface is not shining. When the depth of cut increase, the surface roughness also increase. The results of experiment must consider in different perspective of parameter to get accurate results.

1.3 OBJECTIVES

The objectives of this project are:

(i) To find an optimum parameter (depth of cut - to produce better surface roughness and wheel wear).

(ii) To investigate surface roughness and wear produced during experimental.

(iii) To develop Mathematical model to predict surface roughness using Artificial Neural Network (ANN).

1.4 SCOPES OF THE PROJECT

The scopes of the project are:

a) Use surface grinding machine for grinding process and conventional abrasive (silicon carbide) as a grinding wheel.

b) Use zinc oxide nanocoolant as cutting fluid for grinding process.

c) Use Perthometer to measure surface roughness.

d) Use tachometer to set the work speed constant which was 200 rpm.

e) Use optical measurement to observe microstructure of material.

f) Number of experiments are 18

g) Parameters for the grinding :

   i) Depth of cut, in the range of (5, 7, 9, 11, 13, 15, 17, 19, 21) µm.

1.5 THESIS OUTLINES

Chapter 1 of this thesis is about the background of the grinding process and also nanocoolant. Then it includes the problem caused in grinding process and objective concerning about the investigation of grinding machinability when grind aluminium alloy using water based zinc oxide nanofluid for certain parameters. The scope of this project is to develop a prediction model for surface roughness and wheel wear.

Chapter 2 presents literature review that will focus on recent studies or research by authors related to the grinding machinability when nanocoolant was used as cutting fluid. The formation and characterization of nanocoolant are also discussed here. The literature review can be approximately close to the titles of the project also. From this chapter, the author will get more knowledge on the results of the previous researches and can predict the result for the project.

Chapter 3 is the overview of the preparation of the nanocoolant and experimental work of grinding using conventional abrasive wheel to grind aluminium alloy with zinc oxide nanocoolant. Water based nanocoolant were employed in grinding and the performance was evaluated in terms of surface roughness and wheel wear.

Chapter 4 focuses on the outcomes of the research and discussion. Use perthometer to measure surface roughness. The result need to compare for the grinding process use water based coolant and varies nanocoolant. The model was developed to understand the better machinability in grinding.

Chapter 5 focuses on the conclusions of the project and recommendations for future work. This chapter also will summarize both the results and objectives of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, it basically describes more about the studies on water based grinding and nanocoolants grinding processes which has been done earlier by other researchers. It also discussed about the aluminium alloy and zinc oxide nanocoolant which has been used in this experiment.

2.2 ALUMINIUM ALLOY

Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. It is a versatile heat treatable extruded alloy with medium to high strength capabilities. Based on (V. Songmene et al., 2009) studies, aluminum alloys are among the most commonly used lightweight metallic materials as they offer a number of different interesting mechanical and thermal properties. In addition, they are relatively easy to shape metals, especially in material removal processes, such as machining. In fact, aluminum alloys as a class are considered as the family of materials offering the highest levels of machinability, as compared to other families of lightweight metals such as titanium and magnesium alloys. This machinability quantifies the machining performance, and may be defined for a specific application by various criteria, such as tool life, surface finish, material removal rate and machine-tool power.

2.2.1 Aluminium Alloy Properties

It has been shown that chemical composition (Table 2.1) and physical properties (Table 2.2), structural defects and alloying elements significantly influence machinability (Y. W. Tham et al., 2007). The typical properties of aluminium alloy 6061 include the medium to high strength, good surface finish, good corrosion resistance to sea water and atmospheric conditions, good weldability and brazability, also can be anodized.

Table 2.1: Composition in wt% of Aluminium-6061 Alloy

Composition (weight %)								
Al	**Cr**	**Cu**	**Fe**	**Mg**	**Mn**	**Si**	**Ti**	**Zn**
95.8 - 98.6	0.04 - 0.35	0.15 - 0.04	Max 0.7	0.8 - 1.2	Max 0.15	0.4 - 0.8	Max 0.15	Max 0.25

Source: Y. W. Tham et al., 2007

Table 2.2: Physical Properties of AA6061

Material	**Density (kg/m^3)**	**Melting temperature (°c)**	**Vicker's microhardness (HV)**	**Heat capacity Cp ($Jmol^{-1}$)**	**Ultimate tensile strength(MPa)**
AA6061	2680	582	77	24.28	283

Source: Y. W. Tham et al., 2007

2.2.2 Application of Aluminium Alloy

Aluminium alloys 6061 are used in many applications due to their wide range of excellent properties. The important factors in selecting aluminium (Al) and its alloys are their high strength-to-weight ratio, their resistance to corrosion by many chemicals, their high thermal and electrical conductivity, high ductility, their non-toxicity, reflectivity, and appearance, and their ease of formability and of machinability. Consequently many properties are of importance in each individual application and the alloy development must focus on maximizing one or a combination of properties at the same time as minimum requirements are fulfilled for the others. The principal uses of aluminium and its alloys, in decreasing order of consumption, are in container and packaging (aluminium cans and foil), in building and other types of construction, in transportation (aircraft and aerospace application, buses, automobiles, rail-road cars, an marine craft), in electrical applications (economical and nonmagnetic electrical conductor), in consumer durables (appliances, cooking utensils, and furniture), and in portable tools. Nearly all high voltage transmission wiring is made of aluminium (R. Khettabi et al., 2010).

2.3 GRINDING PROCESS

Grinding is a process carried out with a grinding wheel made up of abrasive grains for removing very fine quantities of material from the work piece surface (Alexius 2008). Low material removal best described for grinding features. The purpose of grinding is to lessen the depth of deformed metal to the point where the last leftovers of damage can be removed by sequence of polishing steps. The scratch depth and the depth of cold worked metal underneath the scratches decrease with decreasing particle have explained the decrease in grinding force as the wheel speed increases as being more due to the favourable kinematic conditions.

Based on (Guhring, 1990) studies, the beneficial effect of more favourable kinematic conditions, and also demonstrates that reduced mechanical strength at elevated temperatures has a critical influence reduction in the grinding tangential force drops with increasing wheel speed and a constant depth of cut. In this case the explanation does not lie in any reduction in the cross section of the chip, as the depth of cut in the groove remains constant. Higher wheel speeds also result in a less ductile behaviour of the material as it is deformed, and so reduce the force and energy input required for the grinding operation.

Machining with grinding wheels is a very complex process affected by so many factors that a reproducible result is rarely obtained. The most important one is that the cutting ability of the grinding wheel changes considerably during the grinding time. In practice, the grinding process is carried out with cutting parameters which are safe but not optimal. The result of a grinding process can be subdivided into characteristics concerning the geometry and surface integrity of a ground component. The geometrical quantities are dimension, shape and waviness, as essential macro-geometric quantities; whereas the roughness condition is the main micro-geometric quantity. The surface integrity state can be described by residual stresses, hardness and structure of the material (Aguiar et al., 2008).

2.4 GRINDING PARAMETER

Grinding is an essential process for final machining of components requiring smooth surfaces and precise tolerances. As compared with other machining processes, grindings costly operation that should be utilized under optimal conditions. Although widely used in industry, grinding remains perhaps the least understood of all machining processes (Rusydah, 2008). The major operating input parameters that influence the output responses, metal removal rate, surface roughness, surface damage, and tool wear, are:

(i) Wheel parameters: abrasives, grain size, grade, structure, binder, shape and dimension.
(ii) Work piece parameters: fracture mode, mechanical properties and chemical composition.
(iii) Process parameters: work speed, depth of cut, feed rate, dressing condition
(iv) Machine parameters: static and dynamic characteristics, spindle system, and table system, etc.

2.4.1 Work piece Material

In this project, the material of work piece used was aluminium alloy. This material is one of the parameters that important which influence the surface roughness in grinding process. The material composition is important in effecting the result of the experiment. It is depends on the chemical composition (Table 2.1) and physical properties in (Table 2.2). Aluminium alloys are alloys in which aluminium (Al) is the predominant metal. Aluminium alloy surfaces will keep their apparent shine in a dry environment due to the formation of a clear, protective layer of aluminium oxide.

2.4.2 Depth of Cut

The second parameter considered in this experimental study is the depth of cut of the work piece during the machining. Depth of cut is a depth of work material removed per revolution or table pass (Rusydah, 2008). Depth of cut is the thickness of material removed in a machining operation as show in Figure 2.2. This studies lead to formulation of factorial design to predict surface roughness with a power form equation using operation-cutting parameters. Decrease of depth of cut improves surface finish (Thomas, 1997). While (Marinescu, 2001), that focused on studying tool vibration, found that increase of depth of cut improves surface roughness under specific operating conditions.

2.4.3 Grinding Wheel

A grinding wheel is an expendable wheel that is composed of an abrasive compound used for various grinding abrasive cutting and abrasive machining operations. They are used in grinding machines. The wheels are generally made from a matrix of coarse particles pressed and bonded together to form a solid, circular shape, various profiles and cross sections are available depending on the intended usage for the wheel (Chris, 2007). They may also be made from a solid steel or aluminium disc with particles bonded to the surface. The manufacture of these wheels is a precise and tightly controlled process, due not only to the inherent safety risks of a spinning disc, but also the composition and uniformity required to prevent that disc from exploding due to the high stresses produced on rotation. The function of the grinding wheel that clamped to the grinding machine are to remove material from a work piece in an abrasive action, each grain acts as a cutting tool, and it is a chip formation process.

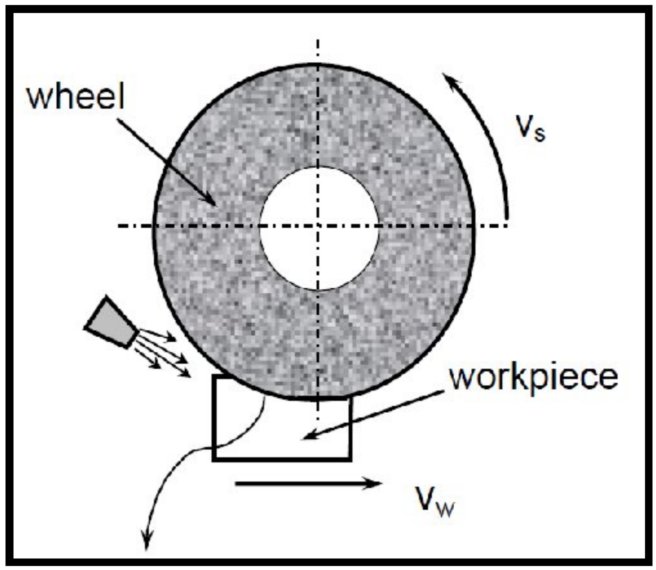

Figure 2.1 : Illustration of Grinding Wheel
Source: Chris. 2007

Silicon carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, refractories, ceramics, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Structural and wear applications are constantly developing. The properties of silicon carbide are as in (Table 2.3). The silicon carbide wheel has low density, high strength, low thermal expansion, high thermal conductivity, high hardness, high elastic modulus, and excellent thermal shock resistance.

Table 2.3: Mechanical Properties of Silicon Carbide

Density	Poisson's Ratio	Hardness	Thermal Conductivity
3.1 gm/cc	0.14	2800 Kg/mm^2	120 W/m•°K

2.5 HEAT TRANSFER IN GRINDING

The grinding process generates an extremely high input of energy per unit volume of material removed. Virtually all this energy is converted to heat, which can cause high temperatures and thermal damage to the work piece such as work piece burn, phase transformations, undesirable residual tensile stresses, cracks, reduced fatigue strength, and thermal distortion and inaccuracies (Bin Shen, 2008).

Temperatures generated during grinding are a direct consequence of the energy input to the process. In general, the energy or power consumption is an uncontrolled output of the grinding process, which may vary considerably and is sensitive to the wheel condition. Consequently, the temperature generated is also uncontrolled and varying. In-process monitoring of the grinding power, when coupled with a thermal analysis of the grinding process, offers a better approach for estimating grinding temperatures and controlling thermal damage.

According to (Xiang, et al., 2006), thermal analyses of grinding processes are usually based upon the application of moving heat source theory to the work piece being ground. For this purpose, the grinding zone is usually modelled as a band source of heat which moves along the surface of the work piece. All the grinding energy expended in considered to be converted to heat at the grinding zone where the wheel interacts with the work piece. A critical parameter needed for calculating the temperature responses is the energy partition to the work piece, which is the fraction of the total grinding energy transported to the work piece as heat at the grinding zone. The energy partition depends on the type of grinding, the wheel and work piece materials, and the operating conditions.

2.6 INTRODUCTION TO SURFACE ROUGHNESS

A surface defined by ANSI as the boundary that separates an object from the surrounding medium. (Mainsah, 2001) stated in his research that feed, nose radius, work material, speed and angle of turning machine has a significant impact on the surface roughness. The Roughness or rugosity is a measurement of the small-scale variations in the height of a physical surface. This is in contrast to large-scale variations, which may be either part of the geometry of the surface or unwanted 'waviness'. Roughness is sometimes an undesirable property, as it may cause friction, wear, drag and fatigue, but it is sometimes beneficial, as its texture allows surfaces to trap lubricants and prevents them from welding together. It is measuring in different ways for different purposes. While, surface roughness defined as the measurement of the finer surface irregularities in the surface texture (Engineredge, 2007). Surface roughness, Ra rated in arithmetic average deviation of the surface valleys and peaks expressed in micro inches or micrometers. The number of grinding parameter that end user needs to understand is quite limited (Marinescu, 2001).

2.6.1 Surface Texture

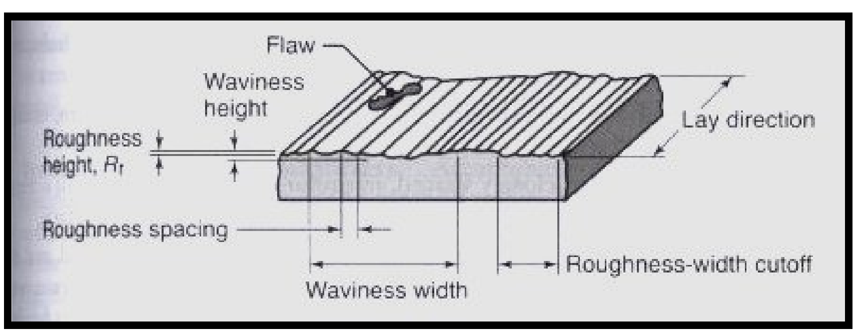

Figure 2.2 : Surface texture

Source : (Kalpakjian, 2001)

Due to production, all surfaces have their own characteristics that referred to surface roughness. The description of surface texture as a geometrical property is complex. Due to the study, the understanding of the surface texture is important to the surface analysis. There are several surface textures define by (Kalpakjian, 2001):

a) Flaws or defects are random irregularities such as scratches, cracks, holes, depressions, seams, tears or inclusions (Figure 2.2)
b) Lay or directionality is the direction of the predominant surface pattern and is usually visible to the naked eye.
c) Roughness is defined as closely spaced, irregular deviations on a scale smaller than that of waviness. Roughness is expressed in terms of its heights, its width, and its distance on the surface along which it is measured.
d) Waviness is a recurrent deviation from a flat surface, much like waves on the surface of water.

Research on surface texture in grinding has yielded several factors that affecting ground surface texture (Figure 2.3), (Erik, et al., 2001).

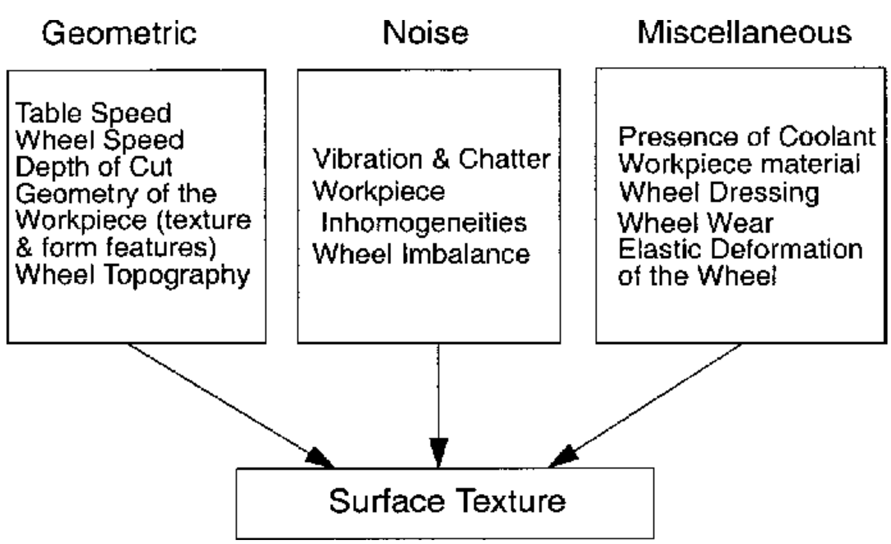

Figure 2.3: Classification of Factors Affecting Ground Surface Texture

Source: Erik, et al., 2001